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DESCRIPTION *In the United States Patent and Trademark Office*

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TO ALL WHOM IT MAY CONCERN:

Be it known that WE, **HIROSHI YOSHIDA, NARUHIKO NOMURA** and **AKIHIRO UENISHI** are all citizens of Japan, whose post office address is c/o **NIPPON STEEL CORPORATION**, Technical Development Bureau, 20-1, Shintomi, Futtsu-shi, Chiba 293-8511, JAPAN, have invented an improvement in

**FRACTURE PREDICTION DEVICE FOR SPOT WELDED PORTION,  
METHOD OF THE SAME, COMPUTER PROGRAM~~SOFTWARE~~  
ARRANGEMENT, AND  
COMPUTER-READABLE RECORDING~~ACCESSIBLE MEDIUM~~**

**CROSS-REFERENCE TO RELATED APPLICATION(S)**

**Technical Field**

**[0001]** This application is a national stage application of PCT Application No. PCT/JP2005/007100 which was filed on April 12, 2005 and published on October 27, 5 2005 as International Publication No. WO 2005/100949, the entire disclosure of which is incorporated herein by reference. This application claims priority from the International Application pursuant to 35 U.S.C. § 365. The present application also claims priority under 35 U.S.C. § 119 from Japanese Patent Application Nos. 2004-118201 and 2005-112644, filed April 13, 2004 and April 8, 2005, respectively.

10 **FIELD OF THE INVENTION**

**[0002]** **[0001]** The present invention relates to a fracture prediction device for a spot welded portion, suitable for use for a spot welding of a structural member for an automobile, and in more detailparticular, for predicting a fracture of the spot welded portion of a member at a time of a collision deformation, to a method thereof, a software 15 arrangement (e.g., a computer program), and a computer-readable recording medium.

**Background Art**

**BACKGROUND INFORMATION**

**[0003]** **[0002]** In recent years, it becomes an urgent problem Recently, it became problematic for an automotive industry to develop a vehicle structure that is capable of 20 eliminating or significantly reducing an injury for a passenger at a time of a collision. The vehicle structure excellent inhaving such a-crashworthiness can be realized obtained such that an impact energy at the time of a collision is absorbed by structural members other than a passenger section, and a deformation of the passenger section is minimized

to thereby securing a survival space. Namely, it is important to make the structural members absorb the impact energy.

**[0004] [0003]** A main structural member absorbing the impact energy at a full-lap crash or an offset crash of an automobile is can be a front side member. In the front side member, the cross section of the member is can be closed by a spot welding after the member is formed by means of a press forming and so on process, etc. Generally, this front side member is can be collapsed to thereby absorb the impact energy. It is important may be beneficial to stabilize a buckling mode and not to make it bend or possibly prevent and reduce its bending and or a fracture halfway, e.g., to improve the absorption of the impact energy.

**[0005] [0004]** There are may exist certain problems such that as a fracture occurs which may occur from a welded point at the time of buckling to cause an unstable buckling mode and the absorption of the impact energy deteriorates, if a spot welding interval, a nugget diameter, and a welding condition are not optimized to stabilize the buckling as for the above-stated spot welding of the member.

**[0005]** Non Patent Document 1: Expository Papers No. 9705JSAESYMPOSIUM

“New Forming Technique of Vehicle Structure”

Non Patent Document 2: JIS Z3136

Non Patent Document 3: JIS Z3137

20 Patent Document 1: Japanese Patent Application Laid-Open No. Hei 6-182561

Patent Document 2: Japanese Patent Application Laid-Open No. 2002-31627

Summary of the Invention

**[0006]** Conventionally, a condition has been ~~investigated~~reviewed to solve the ~~a~~ problem,

in which, for example, a member is buckled stably without fracturing at a welded point by manufacturing members experimentally while changing spot welding intervals

5 variously, and performing a crash test, as shown in Non-Patent Document 1. However, in the above-stated method, trial and error is required in which experimental products are manufactured by each automobile, or by each member to perform the test, and therefore, there was a problem such that a manufacturing cost becomes high and a long time is required to design described in Expository Papers No. 9705 JSAE SYMPOSIUM “New  
10 Forming Technique of Vehicle Structure”.

**[0007]** However, in the above-described method, trial and error should be used in which experimental products are manufactured by each automobile, or by each member to perform the test. Therefore, a problem may exist such that a manufacturing cost becomes high and a long time for design.

15 **[0008]** ~~[0007]~~ Besides, in Patent Document 1, ~~In addition, as described in Japanese~~ Patent Application Laid-Open No. Hei 6-182561, a fracture prevention structure of a welded portion of a floor panel where a load is applied is proposed, but it is a structure only for the floor panel. Therefore, it still required trial and error by the experimental products to obtain a spot welding method in which fracture at the welding points is  
20 prevented in every impact absorbing member, and the impact energy is absorbed by the stable buckling.

**[0009]** ~~[0008]~~ Further, ~~in~~Japanese Patent Document 2, Application Laid-Open No. 2002-31627 describes an optimization of the spot welding interval is proposed, but. However,

it isprovides only a simple index as for individual spot welding strength, and it ismay not provide an accurate prediction for the fracture as it is. Therefore, there was a problem exists in which a design based on an accurate fracture prediction for the spot welded portion wasmay be very difficult or even impossible.

5   **[0010] [0009]** As the index of the strength at the spot welded portion, a shear tension test and a cross tension test defined in Non-Patent Documents 2 and 3 are representatives. There are reported as described in Specifications JIS Z3136 and JIS Z3137 are representative thereof. The examples under various test modes (assuming various load states other than the above, but) in general, describe that a shear tension test value is  
10   treated as a shear strength of the welded portion, and a cross tension test value is treated as a peeling strength of the welded portion by two kinds of tests prescribed in JIS.

**[0011] [0010]** However, the shear strength and the peeling strength of the spot welding obtained by the test can come under a structural influence, such as a width. Therefore, the test value cannot help being corrected and estimated from various points of view in an  
15   actual member. In a system making an optimal design by a collision simulation of an automobile on a computer which is advancing rapidly in recent years, an estimation accuracy thereof is hardlymay not be adequate, and a reliability of the optimal design for a collision safety has likely been deteriorated.

## SUMMARY OF EXEMPLARY EMBODIMENTS OF THE INVENTION

20   **[0012] [0011]** An objectOne of the objects of the present invention is to prevent the fracture of the welded portion of the member at the time of crash deformation, to thereby realize an optimization of a deformed buckling mode, and, Another object of the present invention is to improve the absorbed energy of the crash by judgingdetermining a fracture

prediction for the spot welded portion at the time of the crash deformation ~~by an using, e.g., a prediction model implemented in a finite element method analysis, by the finite element method analysis on the computer not to use a processing arrangement to limit a use of the experimental manufacturing of the member or the collision test.~~

5 [0012] — Substances of the present invention are as stated below.

[0013] (1) A ~~Thus, exemplary embodiments of the present invention are provided.~~

~~According to one exemplary embodiment, a fracture prediction device for a spot welded portion, including: an input means inputting all or any can be provided. Such device can~~

~~include an input arrangement configured to input all or some of a material strength, a~~

10 plate thickness, a nugget diameter of a spot welding, a plate width of a joint, and a rotation angle of the joint plates in a tension test, based on a cross tension test and/or a shear tension test at a spot welded joint; a calculation means calculating. A first

~~calculation arrangement can also be provided which may be configured to calculate a~~

fracture strength parameter of the spot welded portion in a cross tension and/or a shear

15 tension from all or any of the material strength, the plate thickness, the nugget diameter of the spot welding, the plate width of the joint, and the rotation angle of the joint in the tension test; a parameter storage means storing. Further, a parameter storage arrangement

~~can be included which may be configured to store the fracture strength parameter by each~~

steel type; and a calculation means judging a fracture of the spot welded portion by

20 installing the fracture strength parameter stored in the parameter storage means. In

~~addition, a second calculation arrangement may be provide which can be configured to~~

~~determine a fracture of the spot welded portion by installing the fracture strength~~

~~parameter stored in the parameter storage arrangement into a fracture prediction formula~~

in which a deformation at a periphery of the spot welding is modeled by a finite element method.procedure. According to another exemplary embodiment of the present  
invention, the second calculation arrangement can be configured to determine a fracture  
strength parameter in a cross tension and/or a shear tension based on a fracture strength  
5 curve of a spot welded portion asked from all or some of the material strength, the plate  
thickness, the nugget diameter of the spot welding, the plate width of the joint, and the  
rotation angle of the joint in the tension test. The second calculation can further be  
configured to determine a fracture of the spot welded portion by installing the fracture  
strength parameter stored in the parameter storage arrangement into a fracture limit line  
10 in which a deformation at a periphery of the spot welding is modeled by the finite  
element procedure.

(2) — A fracture prediction device for a spot welded portion, including: an input means  
inputting all or any of a material strength, a plate thickness, a nugget diameter of a spot  
welding, a plate width of a joint, and a rotation angle of the joint in a tension test, based  
15 on a cross tension test and/or a shear tension test at a spot welded joint; a calculation  
means calculating a fracture strength parameter in a cross tension and/or a shear tension  
based on a fracture strength curve of a spot welded portion asked from all or any of the  
material strength, the plate thickness, the nugget diameter of the spot welding, the plate  
width of the joint, and the rotation angle of the joint in the tension test; a parameter  
20 storage means storing the fracture strength parameter by each steel type; and a calculation  
means judging a fracture of the spot welded portion by installing the fracture strength  
parameter stored in the parameter storage means into a fracture limit line in which a  
deformation at a periphery of the spot welding is modeled by a finite element method.

(3) — A fracture prediction method for a spot welded portion, including the steps of:  
inputting all or any of a material strength, a plate thickness, a nugget diameter of a spot  
welding, a plate width of a joint, and a rotation angle of the joint in a tension test, based  
on a cross tension test and/or a shear tension test at a spot welded joint; calculating a  
5 fracture strength parameter of the spot welded portion in a cross tension and/or a shear  
tension from all or any of the material strength, the plate thickness, the nugget diameter  
of the spot welding, the plate width of the joint, and the rotation angle of the joint in the  
tension test; storing the fracture strength parameter by each steel type in a parameter  
storage means; and judging a fracture of the spot welded portion by installing the fracture  
10 strength parameter stored in the parameter storage means into a fracture prediction  
formula in which a deformation at a periphery of the spot welding is modeled by a finite  
element method.

(4) — A fracture prediction method for a spot welded portion, including the steps of:  
inputting all or any of a material strength, a plate thickness, a nugget diameter of a spot  
15 welding, a plate width of a joint, and a rotation angle of the joint in a tension test, based  
on a cross tension test and/or a shear tension test at a spot welded joint; calculating a  
fracture strength parameter in a cross tension and/or a shear tension based on a fracture  
strength curve of a spot welded portion asked from all or any of the material strength, the  
plate thickness, the nugget diameter of the spot welding, the plate width of the joint, and  
20 the rotation angle of the joint in the tension test; storing the fracture strength parameter  
by each steel type in a parameter storage means; and judging a fracture of the spot welded  
portion by installing the fracture strength parameter stored in the parameter storage

means into a fracture limit line in which a deformation at a periphery of the spot welding is modeled by a finite element method.

(5) — A computer program for a fracture prediction of a spot welded portion for designing circuit including: program code means for calculating a fracture strength 5 parameter of the spot welded portion in a cross tension and/or a shear tension from all or any of a material strength, a plate thickness, a nugget diameter of a spot welding, a plate width of a joint, and a rotation angle of the joint in a tension test inputted based on a cross tension test and/or a shear tension test at a spot welded joint; program code means for storing the fracture strength parameter by each steel type in a parameter storage means; 10 and program code means for judging a fracture of the spot welded portion by installing the fracture strength parameter stored in the parameter storage means into a fracture prediction formula in which a deformation at a periphery of the spot welding is modeled by a finite element method.

(6) — A computer program for a fracture prediction of a spot welded portion for 15 designing circuit including: program code means for calculating a fracture strength parameter of the spot welded portion in a cross tension and/or a shear tension based on a fracture strength curve of the spot welded portion asked from all or any of a material strength, a plate thickness, a nugget diameter of a spot welding, a plate width of a joint, and a rotation angle of the joint in a tension test inputted based on a cross tension test 20 and/or a shear tension test at a spot welded joint; program code means for storing the fracture strength parameter by each steel type in a parameter storage means; and program code means for judging a fracture of the spot welded portion by installing the fracture strength parameter stored in the parameter storage means into a fracture limit line in

which a deformation at a periphery of the spot welding is modeled by a finite element method.

(7) — A computer readable recording medium recording a computer program for causing a computer to execute the steps, including: calculating a fracture strength 5 parameter of a spot welded portion in a cross tension and/or a shear tension from all or any of a material strength, a plate thickness, a nugget diameter of a spot welding, a plate width of a joint, and a rotation angle of the joint in a tension test inputted based on a cross tension test and/or a shear tension test at a spot welded joint; storing the fracture strength parameter by each steel type in a parameter storage means; and judging a fracture of the 10 spot welded portion by installing the fracture strength parameter stored in the parameter storage means into a fracture prediction formula in which a deformation at a periphery of the spot welding is modeled by a finite element method.

(8) — A computer readable recording medium recording a computer program for causing a computer to execute the steps, including: calculating a fracture strength 15 parameter of a spot welded portion in a cross tension and/or a shear tension based on a fracture strength curve of the spot welded portion asked from all or any of a material strength, a plate thickness, a nugget diameter of a spot welding, a plate width a the joint, and a rotation angle of the joint in a tension test inputted based on a cross tension test and/or a shear tension test at a spot welded joint; storing the fracture strength parameter 20 by each steel type in a parameter storage means; and judging a fracture of the spot welded portion by installing the fracture strength parameter stored in the parameter storage means into a fracture limit line in which a deformation at a periphery of the spot welding is modeled by a finite element method.

Brief Description of the Drawings

**[0014]** In addition, method, software arrangement, and computer accessible medium for a spot welded portion can be provided which performs substantially similar functions as the prediction device described herein above.

5   **[0015]** These and other objects, features and advantages of the present invention will become apparent upon reading the following detailed description of embodiments of the invention, when taken in conjunction with the appended claims.

**BRIEF DESCRIPTION OF THE DRAWINGS**

**[0016]** Further objects, features and advantages of the invention will become apparent from the following detailed description taken in conjunction with the accompanying figure showing illustrative embodiment(s), result(s) and/or feature(s) of the exemplary embodiment(s) of the present invention, in which:

**[0017]** [0013] Fig. 1 is a view showing an illustration of an outline of a method of a shear tension test according to an exemplary embodiment of the present invention;

15   **[0018]** Fig. 2 is a view showing an illustration of an outline of a method of a cross tension test according to an exemplary embodiment of the present invention;

**[0019]** Fig. 3 is a side view at a testing time of the cross tension test of Fig. 2;

**[0020]** Fig. 4 is a view showing an examplegraph of exemplary fracture strength curves;

20   **[0021]** Fig. 5 is a view showing a graph of an exemplary relation between a fracture limit line and calculated strengths Fn, Fs;

**[0022]** Fig. 6 is a view in which relations between graph comparing relationships of a load and a displacement at a time of fracture in the shear tension test are compared between with an experiment and a simulation, that is e.g., FEM;

**[0023]** Fig. 7 is a ~~view~~ in which ~~relations between~~ graph showing relationships of a load and a displacement at a time of a fracture in the cross tension test are compared ~~between~~with an experiment and a simulation, that is e.g., FEM;

**[0024]** Fig. 8 is a block diagram showing an ~~example of a~~exemplary computer system 5 capable of configuring a fracture prediction device for a spot welded portion according to an exemplary embodiment of the present invention;

**[0025]** Fig. 9 is a ~~view~~graph showing a fracture strength curve of an actual exemplary steel plate of 590 MPa grade, and a thickness of 1.8 mm;

**[0026]** Fig. 10 is a ~~view~~graph showing aan exemplary curvilinear relation of “ $\alpha_1$ ” and 10 “d/W” identified by an experiment;

**[0027]** Fig. 11 is a ~~view~~graph in which relations between a load and a displacement at a time of fracture in the shear tension test with a high strength steel of 980 MPa grade, are compared ~~between~~with an experiment and a simulation (FEM);

**[0028]** Fig. 12A is a ~~view~~ showing aan illustration of an exemplary member shape of the 15 high strength steel of 980 MPa grade used for a dynamic axial crush test;

**[0029]** Fig. 12B is a ~~view~~ showing aan illustration of an exemplary result in which a fractured appearance of thean exemplary spot welded portion at the time of a dynamic axial crush test is simulated (FEM); and

**[0030]** Fig. 12C is an exemplary illustration of a photograph showing the fractured 20 appearance of the spot welded portion at the time of the dynamic axial crush test.

Detailed Description of the Preferred Embodiments

**DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS OF INVENTION**

[0031] [0014] Hereinafter, preferred exemplary embodiments of the present invention are described with reference to the drawings. Fig. 1 is a view showing an illustration of an outline of a method of a shear tension test. As For example, as a specimen, two steel plates being base materials 2 are can be overlapped and spot welded as shown in the drawing Fig. 1 to form a nugget 1. A tension test for this such exemplary specimen in directions shown by arrows 3 is can be performed until this specimen fractures. At this time, displacements and loads of the specimen in the tensile directions 3 are may be measured. The fracture occurs can occur at a periphery of the nugget 1, and it becomes to be can become a maximum load at this such time. This value is to can be a fracture limit load “Ftss” (N). When it reaches this limit load “Ftss”, a mean stress “σo” (MPa) inside of the base material is can be “Ftss/W·t” from a width “W” (mm) and a plate thickness “t” (mm) of the base material 2.

[0032] [0015] At the periphery of the nugget 1 to be a which is an initiation point of the fracture, a stress concentration factor “α” at an end portion of the nugget 1 and the base materials 2 can be defined as shown in a formula (1) as a fraction of a tensile strength “TS” of the base material and the mean tensile stress “σo” of the base material when a maximum stress is assumed to reach the tensile strength “TS” (MPa).

20 
$$\alpha = TS/\sigma_o = TS \cdot W \cdot t / Ftss \dots (1)$$

[0033] [0016] The fracture limit loads “Ftss” are can be measured by materials with various tensile strengths “TS” and various specimen widths “W”, plate thicknesses “t”, and nugget diameters “d” (mm), and thereby. Thus, this stress concentration factor “α”

is can be calculated from the using formula (1) to create a table as a database. Herewith, the The fracture limit load “Ftss” with an arbitrary tensile strength “TS”, plate thickness “t”, width “W”, and nugget diameter “d” can be predicted with a formula (2) by using the stress concentration factor “ $\alpha$ ” in the table.

5

$$Ftss = TS \cdot W \cdot t / \alpha \dots (2)$$

**[0034] [0017]** Besides Further, the stress concentration factor “ $\alpha$ ” becomes to be can become a curve by organizing with a fraction “d/W” of the nugget diameter “d” and the width “W”. Therefore, the “Ftss” may be predicted from the using formula (2) by using the “ $\alpha$ ” calculated from a formula (3).

10

$$\alpha = k / (p \cdot d / W - q) + r \dots (3)$$

15

**[0035]** Here, the “k, p, q, n, and r” are can be the parameters to perform a fitting of a curvilinear relation of the “ $\alpha$ ” and the “d/W” with the using formula (3), and they are. These parameters can preferable to be in the ranges as follows: k = 0.001 to 100; p = 0.01 to 100; q = -10 to 10; n = 1 to 10; and r = -100 to 100. However, the an exemplary formula can remove or limit the need to make the fitting of the curve is not necessarily to have a format of the formula (3), and it may be the a formula capable of fitting the curvilinear relation. Besides, the In addition, “ $\alpha$ ” may be read from the graph of the curve directly without using the formula (3).

20

**[0036] [0018]** Next, a member in an arbitrary shape welded by the spot welding is can be modeled by using a finite element method on procedure, e.g., using a processing arrangement (e.g., a computer). A shear force “Fs” (N) in a direction along a member surface of an element connecting members with each other in which the spot welding is may be modeled, and a. A vertical force “Fn” (N) in a direction connecting members

with each other orthogonal to the shear force “Fs” (N) ~~are can be~~ calculated by the ~~computer processing arrangement~~ one after another during a deformation of a collision analysis reproduced by using the finite element method. This calculation ~~means arrangement~~ of the “Fs” and “Fn” ~~depends can depend~~ on a general analysis code, 5 for example, refer to “PAM-CRASH v2002 user’s manual” made by ESI Co., Ltd.. A fracture judgment on the ~~computer is processing arrangement~~ can be set at the time when a formula (4) becomes true.

$$Fn^2 + Fs^2 \geq Ftss^2 \dots (4)$$

[0037] [0019] Fig. 2 is a view showing an illustration of an outline of a cross tension test. As the according to the exemplary embodiment of the present invention. 10 The specimen, includes two steel plates being that are the base materials 2 are overlapped and spot welded as shown in the drawing Fig. 2 to form the nugget 1. A tension test for this specimen is can be performed in the directions shown by the arrows 3 until this specimen fractures. At this such time, the displacements and the loads of the specimen in 15 the tensile directions 3 are may be measured. The fracture occurs can occur at the periphery of the nugget 1, and it becomes to may be considered the maximum load at this time. This value is can be set as a fracture limit load “Fcts” (N). When it reaches this limit load “Fcts”, the mean stress “σo” (MPa) inside of a plate surface of the base material is to can be “Fcts/(2W·t·sin θ)” from the width “W” (mm) and the plate thickness 20 “t” (mm) of the base material 2 by using an angle “θ” shown in Fig. 3.

[0038] [0020] At the periphery of the nugget 1 which is intended to be the initiation point of the fracture, the stress concentration factor “α” at the end portion of the nugget 1 and the base material 2 can be defined as shown in using formula (5) as the fraction of the

tensile strength “TS” (MPa) of the base material and the mean tensile stress “ $\sigma_0$ ” (MPa) of the base material if the maximum stress is assumed to reach the tensile strength “TS” (MPa).

$$\alpha = TS/\sigma_0 = TS \cdot W \cdot t / Fcts \dots (5)$$

5 [0039] [0021] This is completely Formula 5 has the same format as the formula (1) asked polled by the shear tension test, and an angle correction “ $\theta$ ” is added because the tensile directions are different. Consequently, the fracture limit load “Fcts” can be calculated by ausing formula (6) with an arbitrary material, width, plate thickness, and nugget diameter by using, e.g., the same method or similar procedure as the shear tension 10 test.

$$Fcts = 2 \cdot TS \cdot W \cdot t \cdot \sin \theta / \alpha \dots (6)$$

[0040] [0022] As same as the case in the shear tension, a fracture judgment of the spot welded portion in an arbitrary member at the time of the collision deformation is regarded to be at the time when a formula (7) becomes true on the computer processing 15 arrangement.

$$Fn \geq Fcts \dots (7)$$

[0041] [0023] As stated described above, the fracture limit loads, that is fracture strength parameter “Ftss” and “Fcts” are can be calculated by the formula (1), formula (2), formula (3), formula formulas (1)-(3), (5), and formula (6), the collision deformation is may be 20 analyzed by the finite element method procedure with the arbitrary member, and the fracture judgment of the spot welding is set to be at the time when either the formula (4) and/or the formula (7) becomes true first or when they become true at the same or similar

time or ~~one~~a formula into which the formula (4) and formula (7) ~~is~~can be combined becomes true.

**[0042] [0024]** When the form of the deformation is known from the shape of the member and an input method of the load, ~~only~~e.g., one of the formula (4) or the formula (7) may

5 be calculated on the ~~computer~~processing arrangement to make a ~~judged~~determination.

Besides, the fraction between the “Fn” and the “Fs” is calculated on the ~~computer~~processing arrangement one after another, and the fracture ~~judgment~~determination may be made, for example, by using the formula (7) when  $Fn > 3Fs$ , and the formula (4) in certain other cases.

10 **[0043] [0025]** Herewith~~Thus~~, it ~~becomes~~is possible to predict the fracture judgment of the spot welding on the ~~computer~~processing arrangement accurately, e.g., without verifying by creating the member and performing the collision test actually. It ~~becomes~~According to an exemplary embodiment of the present invention, it is possible to investigate a condition in which the spot welding does not fracture by varying the 15 member shape, the material, the plate thickness, the nugget diameter, and a welding position on the computer by using this ~~method~~procedure, and an optimal member can be designed.

**[0044] [0026]** As for the fracture limit load of the spot welding ~~especially~~, e.g., when the tensile strength “TS” of the material is larger than 590 (MPa), it ~~is~~can be suitable to

20 calculate the “Ftss” in the shear tension test by using the following formula (2’), formula (3m) instead of the formula (2), formula (3), and the “Fcts” in the cross tension test by using the following formula (3m2), formula (3m3), formula (3m4), and formula (6’)

instead of the formula (3), formula (6), different from the above-stated method described procedure.

$$F_{tss} = TS \cdot W \cdot t / \alpha_1 \dots (2')$$

$$\alpha_1 = (e (TS/f - g)^h - i) / (d/W)^j + 1 \dots (3m)$$

5 **[0045]** Here, the “e, f, g, h, i, and j” are parameters to perform a fitting of a curvilinear relation of the “ $\alpha_1$ ” and the “d/W” with the formula (3m), and they are within the ranges as follows: e = 0.0001 to 100; f = 100 to 2500 (MPa); g = 0.1 to 10; h = 0.0001 to 10; i = 0.01 to 100; and j = 1 to 100.

$$F_{cts} = 2 \cdot TS \cdot W \cdot t \cdot \sin \theta / \alpha_2 \dots (6')$$

10  $\alpha_2 = \beta / (d/W) \chi + \delta \dots (3m2)$

$$\chi = \varphi (TS/\gamma - \eta) \psi - \xi \dots (3m3)$$

$$\delta = \lambda (TS/\mu - \rho) \omega - \zeta \dots (3m4)$$

**[0046]** Here, the “b, c, d, f, g, h, Y, x, l, m, r, w, and z”  $\beta, \chi, \delta, \Phi, \gamma, \eta, \Psi, \xi, \lambda, \mu, \rho, \omega$ , and  $\zeta$  are parameters to perform a fitting of a curvilinear relation of the “ $\alpha_2$ ” and the “d/W” with the formula (3m2), formula (3m3), and formula (3m4), and they are within the ranges as follows:  $b\beta$  = 0.0001 to 100;  $f\chi$  = 0.1 to 100;  $g\Psi$  = 100 to 2500 (MPa);  $h\eta$  = 0.1 to 10;  $Y\Psi$  = 0.0001 to 100;  $x\xi$  = 0.01 to 100;  $l\lambda$  = 0.01 to 100;  $m\mu$  = 100 to 2500 (MPa);  $r\rho$  = 0.1 to 10;  $w\omega$  = 0.0001 to 100; and  $z\zeta$  = 0.01 to 100.

15 **[0047]** **[0027]** The A formula to make the fitting of the curve is not necessarily needed to be the formats of these exemplary formulas, and it is good enough as long as it can may be used to make the fitting of the curvilinear relation. Besides Further, the curvilinear relation of the “ $\alpha_1$ ” or the “ $\alpha_2$ ” and the “d/W” becomes can become one curve by each

strength grade without using these formulas, and therefore, the “aq1” or the “aq2” can be identified directly from each graph of the curve.

**[0048] [0028]** Fig. 4 is a view schematically showing a method to calculate the fracture limit load by using a graph based on experimental data, in addition to the method to 5 calculate the fracture limit load by using the formulas such as the formula (1), formula (2), formula (3), and formula (5), formula (6), or the formula (3m), formula (3m2), formula (3m3), and formula (3m4) instead of the formula (3). The fracture limit loads arecan be measured by the test in which the “dδ/W” is varied and when it is graphed, the fracture load curves can be written in various curvilinear relations depending on the 10 material strength TS. Here, the material strengths are TS1 < TS2 < TS3. The fracture limit load corresponding to the condition can be identified from these curves directly. This curve becomes a fracture limit load curved surface by taking the plate thickness “t” as a third axis, and the fracture limit load can be identified by reading a value on the curved surface at an arbitrary plate thickness “t”, the material strength “TS”, the width 15 “W”, and the nugget diameter “d”.

**[0049] [0029]** In this manner, the material strengths can be TS1 < TS2 < TS3. The fracture limit load corresponding to the condition can be identified from these curves directly. This curve becomes a fracture limit load curved surface by taking the plate thickness “t” as a third axis, and the fracture limit load can be identified by reading a value on the curved 20 surface at an arbitrary plate thickness “t”, the material strength “TS”, the width “W”, and the nugget diameter “d”.

**[0050] [0029]** Further, a fracture limit line iscan be created as shown in Fig. 5 by using the fracture limit loads identified by the various rotation angles “q” instead of using the

formula (4) and formula (7). This fracture limit line and the “Fn”, “Fs” calculated one after another by the analysis of the finite element method ~~are~~may be compared, and it may be judged as the fracture when the “Fn”, “Fs” come to on the curve and at outside of the curve.

5    **[0051] [0030]** This ~~method~~exemplary procedure can be applied not only to steel material but also to every other material. Besides, ~~it~~Further, such procedure can be applied not only to every welding such as a laser welding, an arc welding, a seam welding, and a mash-seam welding, but also to the spot welding, and further, to every mechanical bonding such as a TOX bonding and a rivet bonding, a friction bonding, a diffusion bonding, a friction diffusion bonding, a friction stir welding and every bonding by using 10 an adhesive agent. The calculation ~~method~~procedure on the ~~computer~~processing arrangement can be applied to a boundary element ~~method~~procedure, a difference ~~method~~procedure, a meshless ~~method~~procedure, an elementary analysis, and every calculation ~~method~~procedure without limiting to the finite element ~~method~~procedure, and 15 it can be applied to a calculation ~~method~~procedure independent of a material mechanics and a ~~computer~~the processing arrangement.

**[0052] [0031]** The calculation ~~method~~procedure of the stress concentration factor “ $a_g$ ” by ~~means of~~using the experiment is not also limited to the above-stated shear tension test, cross tension test, and it can be calculated by using every shape of specimen, and a load 20 applying ~~method~~procedure.

**[0053] [0032]** The above-stated prediction of the fracture judgment can be applied not only to the collision analysis of the whole automobile and member, but also to

components other than the automobile, and it goes without saying that it can be applied to an analysis in a quasi-static deformation other than a collision.

**[0054] [0033]** Fig. 8 is a block diagram showing an example of a computer system capable of configuring a fracture prediction device for a spot welded portion. In the drawing, Fig. 8, a reference numeral 1200 is a computer PC. The PC 1200 includes a CPU 1201, ~~executescan execute~~ a device control software stored in a ROM 1202 or a hard disk (HD) 1211, or supplied from a flexible disk drive (FD) 1212, and ~~totallymay~~ controls respective devices connected to a system bus 1204.

**[0055] [0034]** Respective function means ~~of arrangement of an exemplary embodiment~~ according to the present embodiment ~~invention~~ are constituted by, e.g., programs stored in the above-stated CPU 1201, ROM 1202, or hard disk (HD) 1211 of the PC 1200.

**[0056] [0035]** Reference numeral 1203 is a RAM, and it ~~functions~~ can function as a main memory, a work area, ~~and so on etc.~~ of the CPU 1201. Reference numeral 1205 is a keyboard controller (KBC), and it controls ~~to~~ may control input signals inputted from a keyboard (KB) 1209 to the system main body. Reference numeral 1206 is a display controller (CRTC), and it ~~performs~~ can perform a display control on a display device (CRT) 1210. Reference numeral 1207 is a disk controller (DKC), and it ~~controls~~ can control an access with the hard disk (HD) 1211 and the flexible disk (FD) 1212, storing a boot program (a program starting an execution (operation) of hardwares and softwares of a personal computer), plural application programs, edit files, user files, network management programs, and so on.

**[0057] [0036]** Reference numeral 1208 is a network interface card (NIC), and it performs ~~can perform~~ interactive data exchanges with a network printer, other network devices, or other PCs via a LAN 1220.

**[0058] [0037]** The above-stated ~~described~~ functions of the exemplary embodiment of the present invention can also be ~~realized obtained~~ by the an execution of the program by the computer processing arrangement. Besides, means an arrangement configured to supply a computer the processing arrangement with the computer program, for example, a computer readable recording medium or computer accessible medium such as a CD-ROM and so on recording, etc. which is configured to record such program, or a transmission medium such as an internet transmitting such the program can be applied utilized as the an exemplary embodiment of the present invention. Besides Further, a computer program product such as the computer readable recording accessible medium recording which records the above-stated ~~described~~ program can also be applied utilized as the an exemplary embodiment of the present invention. The above-stated ~~described~~ computer program, recording medium, computer accessible medium, transmission medium, and computer program product are included within a range can be utilized according to an exemplary embodiment of the present invention. As the recording media, for example, a flexible disk, a hard disk, an optical disk, a magnetic optical disk, a CD-ROM, a magnetic tape, a nonvolatile memory, a ROM, and so on etc. can be used.

20 **[0038] (Example 1)**

**[0059]** A An exemplary embodiment of a system is according to the present invention can be structured in which the above-stated fracture prediction model is used, and a fracture of a spot welded portion is judged automatically while analyzing a collision deformation

of a member, as a subroutine program in a general collision analysis FEM code. The used code is “PAM-CRASH v2002” made by ESI Co., Ltd., and the spot welded portion is modeled by using a “Multi-PLINK” as for the member modeled by a shell element.

**[0060] [0039]** A comparison of an analysis, in which a shear tension test and a cross

5 tension test are modeled as they are, and an experiment is the best for an accuracy verification of the fracture prediction model, because an exact comparison becomes possible. Therefore, a shear tension specimen and a cross tension specimen are created with a steel plate of 590 MPa grade and a thickness “ $t$ ” = 1.8 (mm), according to JIS standards of 3136, 3137. A nugget diameter of the spot welding is  $5\sqrt{t}$  (mm). A test is  
10 performed by using an Instron type testing machine, and loads and displacements until a spot welded portion fractures are measured at that time. At the same time, the shear tension test and the cross tension test in the same forms as the test are modeled on the ~~computer~~processing arrangement, an analysis of the tension test is performed by the FEM code mounting the above-stated subroutine program to judge the fracture of the spot  
15 welded portion automatically, and the loads and the displacements until the spot welding fractures as same as the experiment are calculated. Inputted initial parameters of “TS” = 642 (MPa), “ $t$ ” = 1.8 (mm), “ $d$ ” = 6.7 (mm), “ $\theta$ ” = 23°, are set as common parameters.

In the shear tension test, the following values are used.

$$\text{“a}_{\underline{\alpha}}\text{”} = 1.80 (-), \text{“W”} = 40 (\text{mm})$$

20 In the cross tension test, the following values are used.

$$\text{“a}_{\underline{\alpha}}\text{”} = 2.17 (-), \text{“W”} = 50 (\text{mm})$$

**[0061]** The fracture strength parameters “ $F_{tss}$ ” = 25680 (N), “ $F_{cts}$ ” = 20798 (N) obtained by the above are installed in a fracture prediction formula in which a deformation at a

periphery of the spot welding is modeled by the finite element method, to thereby judge the fracture of the spot welded portion.

[0062] [0040] The test model is created may be generated by the shell element of which collision analysis level of a full vehicle is rough, and a boundary condition is also

5 simplified with considering that they can be applied for the collision analysis of an actual member.

[0063] [0041] Fig. 6 and Fig. 7 are verification graphs of examples of this for verifying this exemplary system. Reference numeral 4 represents a simulation of a shear tension specimen, and reference numeral 5 represents a simulation of a cross tension specimen.

10 Fracture modes are respectively different in the shear tension test and the cross tension test. However, it turns out that the fracture loads on the load - stroke curves of the experiment and the FEM analysis are matched. In the shear tension test, it seems that the shapes of the load - displacement curves until they reach the fracture load are different between in the experiment and the analysis. However, they just seem appear to be

15 different because a specimen chuck is connected to a crosshead via a universal joint in the experiment, and therefore, a rotation of the chuck portion occurs at a time of load rising, but this rotation is not considered in the analysis because of the simplification of the model. This may just change a behavior of an initial stroke change, and therefore, it does not essentially affect on the load at the time of the fracture occurrence. Behaviors of

20 the load - displacement curves are slightly different between in the experiment and in the analysis also in the cross tension test, but it is similarly a problem of the chuck of the experiment. Therefore, it only affects on the initial behavior and the experiment and the analysis are matched at the fracture loads. Of course, if it is modeled with including the

chuck portion on the analysis, the behavior of this portion may be matched with the experiment, but here, it is skipped because it is not an essential problem. This rather shows the following that it is possible to predict the spot fracture accurately in an analysis at practical level in which detailed portions are simplified in a large-scaled collision

5 analysis of an entire model or a partial model of the full vehicle, because the fracture load of an actual test can be predicted accurately even by the FEM analysis in which the test is modeled in a simple manner.

**[0064]** Behaviors of the load - displacement curves are slightly different between in the experiment and in the analysis also in the cross tension test, but it is similarly a problem

10 of the chuck of the experiment. Therefore, it only affects on the initial behavior and the experiment and the analysis are matched at the fracture loads. Of course, if it is modeled with including the chuck portion on the analysis, the behavior of this portion may be matched with the experiment, but here, it is skipped because it is not an essential problem. This shows that it is possible to predict the spot fracture accurately in an

15 analysis at practical level in which detailed portions are simplified in a large-scaled collision analysis of an entire model or a partial model of the full vehicle, because the fracture load of an actual test can be predicted accurately even by the FEM analysis in which the test is modeled in a simple manner.

**[0065] [0042]** As stated described above, it can be verified that this is the analysis

20 method procedure capable of predicting the fracture of the spot welding accurately by a basic test. Besides can be utilized. Further, the prediction of the spot welding fracture at the time of the collision deformation in a component level is can be verified from both experimental side and experimentally and using an exemplary analysis side, and it is

confirmed that the fracture prediction in the analysis is matched with the experiment.

The system is confirmed to be a system capable of controlling and designing a deformation mode of members and an absorption energy based on the above, because the fracture of the spot welded portion can be predicted.

5    **[0066]** **[0043]** This methodprocedure can be installed to general solverssolver processing arrangements, such as “LS-DYNA3D” made by LSTC Co., Ltd., “RADIOSS” made by MECALOG Co., Ltd., and to a solver developed individually, in addition to the general solver “PAM-CRASH”. BesidesFurther, the model and procedure of the spot welded portion ismay be applicable for a beam element, a shell element, a solid element, and so 10 on, in addition to a contact type such as the “Multi-PLINK”.

**[0044]** (Example 2)

**[0067]** Next, aA verification of a prediction accuracy of a shear tensile strength is performed by using a fracture strength curve. Material thereof iscan be a steel plate of

15    590 MPa grade, a thickness = 1.8 (mm) as same as described in the exampleExample 1. At firstInitially, a width “W” of a specimen of the shear tension test iscan be varied from 20 (mm) to 50 (mm), at the same time, a nugget diameter “d” is also varied from 4 (mm) to 7 (mm) to perform the test, and a fracture strength parameter “Ftss” is actually measured. AAn exemplary fracture strength curve shown in Fig. 9 can be obtained from

20    the results of the test. The fracture strength parameter “Ftss” = 25.5 (kN) can be read from the fracture strength curve as shown by a circular sign in Fig. 9, under a condition of “d” = 6.7 (mm), “W” = 40 (mm) which is the same condition as in the example 1.

This is approximately the same value with the “Ftss” under the same condition in the

example 1. It can be confirmed that the The fracture loads are generally matched on the load - stroke curves of the experiment and the FEM analysis as shown in Fig. 6, by performing a finite element method (FEM) analysis in the following, in which the test is modeled as same as in the example 1. Consequently, if Fig. 6 shows that the fracture

5 strength parameters under any condition in practical use can be obtained by creating the fracture strength curve with varying the width “W” and the nugget diameter “d” within a wide range corresponding to the actual use. The case when the material strength and the plate thickness are fixed is shown in the above, but when the strength and the plate thickness vary, the fracture strength curves are to be created respectively.

10 **[0045]** (Example 3)

**[0068]** Next, aIn addition, an exemplary system iscan be structured in whichsuch that a fracture prediction model when a tensile strength thereof is larger than 590 MPa grade is used, and a fracture of a spot welded portion is automatically judged while analyzing a collision deformation of a member as a subroutine program in the general collision analysis FEM code. The used code is “PAM-CRASH v2003” made by ESI Co., Ltd., and the spot welded portion of a member which is modeled by a shell element is modeled by using “Multi-PLINK”.

**[0069]** [0046] A comparison of an analysis, in which the shear tension test iscan be modeled as itis, and an experiment is the bestpreferable for an accuracy verification of the fracture prediction model, because an exact comparison becomes possible. Therefore, 20 a shear tension specimen iscan be created with a steel plate of 980 MPa grade and a thickness “t” = 1.4 (mm) as same as in the example 1. A nugget diameter of the spot welding is  $6\sqrt{t}$  (mm). A test ismay be performed by using an Instron type testing

machine, and the loads and the displacements until the spot welded portion fractures are measured. At the samesuch time, the shear tension test in the same form as the test iscan be modeled on the computer, anprocessing arrangement, anexemplary analysis of the tension test is performed by the FEM code mounting the above-stated subroutine program

5 to judge the fracture of the spot welded portion automatically, and the loads and displacements until the spot welding fractures as same as the experiment are calculated.

Inputted initial parameters of “TS” = 983 (MPa), “t” = 1.4 (mm), “d” = 7.2 (mm), “ $\theta$ ” = 23°, “ $a_1$ ” = 2.12 (-), and “W” = 40 (mm) are used. The “ $a_1$ ” is determined by reading from a graph of the curve of the “ $a_1$ ” and the “ $d/W$ ” asked by the experiment as shown

10 in anexemplary graph of Fig. 10. A fracture strength parameter “ $F_{tss}$ ” = 26340 (N) obtained by the above is installed to a fracture prediction formula in which a deformation at a periphery of the spot welding is modeled by a finite element method, to judge the fracture of the spot welded portion.

**[0070] [0047]** The test model iscan be created by a shell element of which collision analysis level of a full vehicle is rough, and a boundary condition is also simplified with considering that they can be applied for the collision analysis of an actual member.

**[0071] [0048]** Fig. 11 isshows a graph of a verification-example of this exemplary system, and it can be seenwhich demonstrates that the fracture loads on the load - stroke curves of the experiment and the FEM analysis arecan be matched in the shear tension

20 test. It seems that the The shapes of the load - displacement curves until they reach the fracture loads are different between the experiment and the analysis in the shear tension test, but the cause is the same or similar as the one statedcause indicated in the example 4 and there is no problem 1, without problems.

**[0072] [0049]** Further, a verification of a prediction model ~~is~~can be performed by an axial crush test of a simple member. As shown in an exemplary illustration of Fig. 12A, a member 6 ~~is~~can be constituted by a spot welding of a hat shape in cross section and an attached closure plate, and a hat top portion, perpendicular walls are 50 (mm) respectively, flanges are 20 (mm), and a length in a crush direction is 300 (mm).

5 Material Exemplary material used for the member is a steel product of 980 MPa grade ~~as~~may be same as the above, and the nugget diameter of the spot welding is  $4\sqrt{t}$  (mm). A dynamic crush test ~~is~~can be performed under a condition that a weight of a drop hammer is 500 (kg), an initial speed at the time of the crush is 6 (m/s), and the FEM analysis is

10 performed under the same condition. The test result and the FEM analysis result are compared by the shapes of the members after the crush as shown in Fig. 12B showing a simulation 7, and Fig. 12C showing an actual experiment. As a result, shapes of buckling are the same, and in particular, both patterns are matched in which the spot welded portion fractures, and thereby, the attached closure plate is detached. Herewith, it is

15 shown that the spot fracture can be predicted accurately by an analysis at practical level in which detailed portions are simplified, in a large-scaled collision analysis of an entire model and a partial model of a full vehicle.

**[0073]** The exemplary test result and the exemplary FEM analysis result can be compared by the shapes of the members after the crush as shown in Fig. 12B showing a simulation 7, and Fig. 12C showing an actual experiment. As a result, shapes of buckling are the same, and in particular, both patterns can be matched in which the spot welded portion fractures, and thereby, the attached closure plate ~~may be~~ detached. Herewith, it is shown that the spot fracture can be predicted accurately by an analysis at practical level

in which detailed portions are simplified, in a large-scaled collision analysis of an entire model and a partial model of a full vehicle.

Industrial Applicability

[0074] [0050] According to exemplary embodiments of the present invention, it is  
5 possible to perform a fracture prediction accurately at a portion in which, for example, a spot welding of an automobile member is modeled by a finite element method analysis on a computer. Therefore, a verification of the fracture of the spot welded portion at a time of a collision test by using an actual automobile member can be skipped, and/or the number of times of the verification test can be reduced drastically. BesidesFurther, for  
10 example, experimental manufactures with varying a spot welding condition of the automobile member, a member design preventing or reducing the spot welding fracture by means ofusing a large-scaled experiment of a collision test, can be replaced by a design preventing or reduce the fracture of the spot welded portion by the collision analysis on the computer, and thereforeusing the processing arrangement. Therefore, it is  
15 possible to contribute to a significant cost reduction and a shortening of a design and development period.

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